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## Summary

### Bpm sensitivity

1% standard deviation (100um over 10mm)

### Bpm linearity (sample of 1)

300um error over 10mm change

Correction may require knowledge of orthogonal position

### A/D errors

Noise reduced with number of samples or limited bandwidth

Integral Nonlinearity (INL) typical  $\frac{1}{2}$  LSB but 2lsb max

Measure ~200um error over limited range

Difficult to correct

Rotational errors are important

1degree would cause 100um error over 10mm change

It would be good to measure cooling region bpm's with a matched preamp

# **Comparison of 12 and 14 bit A/D Converters for use in a bpm Receiver**

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## **Introduction:**

Definitions, measurements, and calculations are presented that will influence the choice of an A/D converter for a BPM system. Two A/D's stand out: the AD6644 which is 14-bit 100 MSPS and the AD9430 which is 12-bit 210 MSPS. These represent the current state of the art.

## **Definitions:**

### DNL – differential non-linearity

The deviation of any code width from an ideal 1 LSB step

### INL – integral non-linearity

The deviation of the transfer function from a reference line measured in fractions of 1 LSB using a “best straight line” determined by a least-square curve fit.

### SINAD – signal to noise and distortion

The ratio of the rms signal amplitude (set 1db below full scale) to the rms value of the sum of all other spectral components, including harmonics, but excluding dc.

### SNR – signal to noise ratio

The ratio of the rms signal amplitude (set 1db below full scale) to the rms value of the sum of all other spectral components, excluding the first five harmonics and dc.

### ENOB – effective number of bits

$$ENOB = \frac{SNR_{db} - 20 \log \sqrt{\frac{3}{2}}}{20 \log 2}$$

$$\text{for an ideal } N \text{ bit A/D} \quad SNR = 2^N \sqrt{\frac{3}{2}}$$

$$rms = \sqrt{\frac{1}{T} \int_0^T V^2 dt} \quad V = \frac{LSB}{2} \left( t \frac{2}{T} - 1 \right) \quad \text{for } t = 0 \text{ to } T$$

$$\begin{aligned} rms \text{ Error} &= \frac{LSB}{2} \sqrt{\frac{1}{T} \int_0^T \left( t \frac{2}{T} - 1 \right)^2 dt} \\ &= \frac{LSB}{2\sqrt{3}} \end{aligned}$$

$$\text{for Signal} = \frac{2^N \text{ LSB}}{2} \sin(\omega t)$$

$$\text{rms Signal} = \frac{2^N \text{ LSB}}{2\sqrt{2}}$$

$$SNR = 2^N \sqrt{\frac{3}{2}}$$

### Aperture Delay

The delay between the 50% point of the rising edge of the ENCODE command and the instant at which the analog input is sampled.

### AU - Aperture Uncertainty

The sample to sample variation in aperture delay.

$$\text{error} = AU \frac{d}{dt} V_{signal}$$

$$SNR = \frac{V_{signal}}{V_{error}} = AU 2\pi f_{signal} \quad (\text{wrt signal})$$

### Position:

The beam position can be estimated from the relative amplitude of the signals produced on the electrodes. The sensitivity of a bpm is proportional to the electrode separation or radius of the aperture.

$$pos \approx R \frac{A - B}{A + B} \approx \frac{R}{1.14} \log \frac{A}{B} = \frac{R}{1.14 \times 20} \frac{A}{B} \Big|_{db}$$

Note: A/B = 10 (20db) indicates a beam position at the surface of the electrodes.

Position error for A=B=full scale and the noise (or error) is the same magnitude but uncorrelated in A and B.

Linearity error cannot be improved with averaging. The linearity error is estimated below for A=B=full scale.

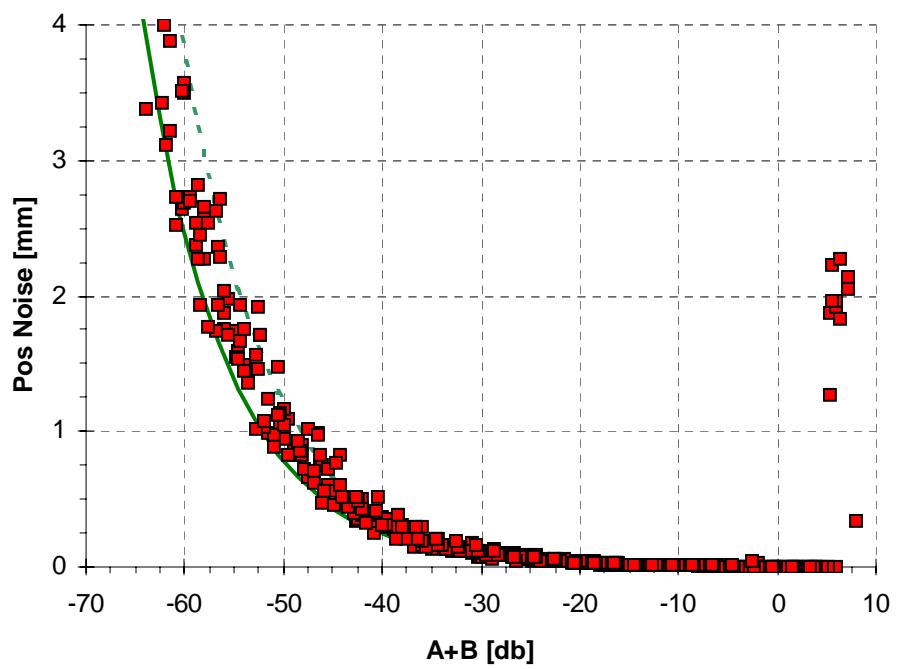
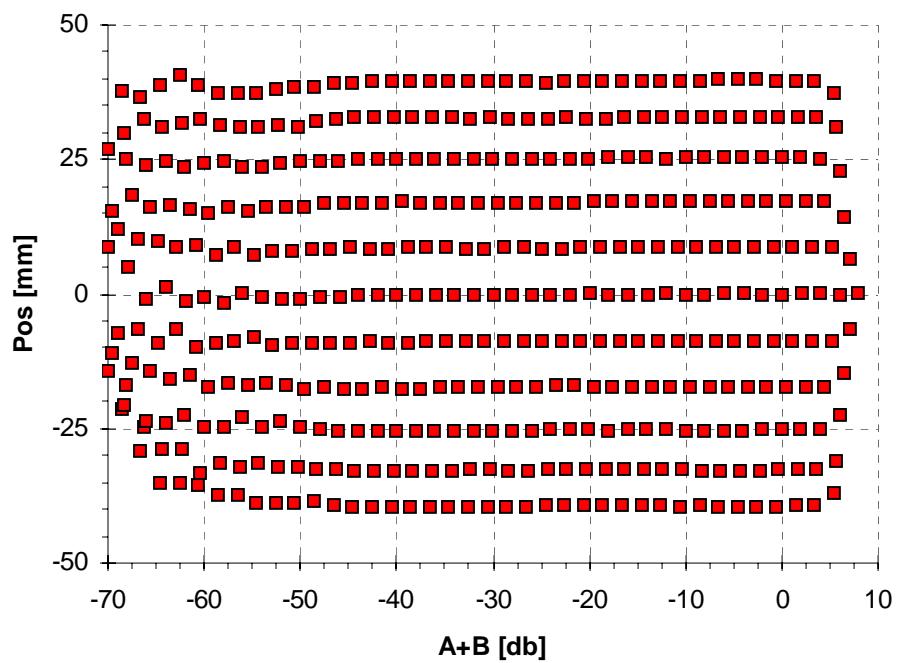
$$\text{linearity pos error} = R \frac{A_{err} - B_{err}}{A_{sig} + B_{sig}} \approx R \frac{\sqrt{2} A_{err}}{2 A_{sig}} = R \frac{1}{\sqrt{2}} \frac{2^{INL}}{2^N}$$

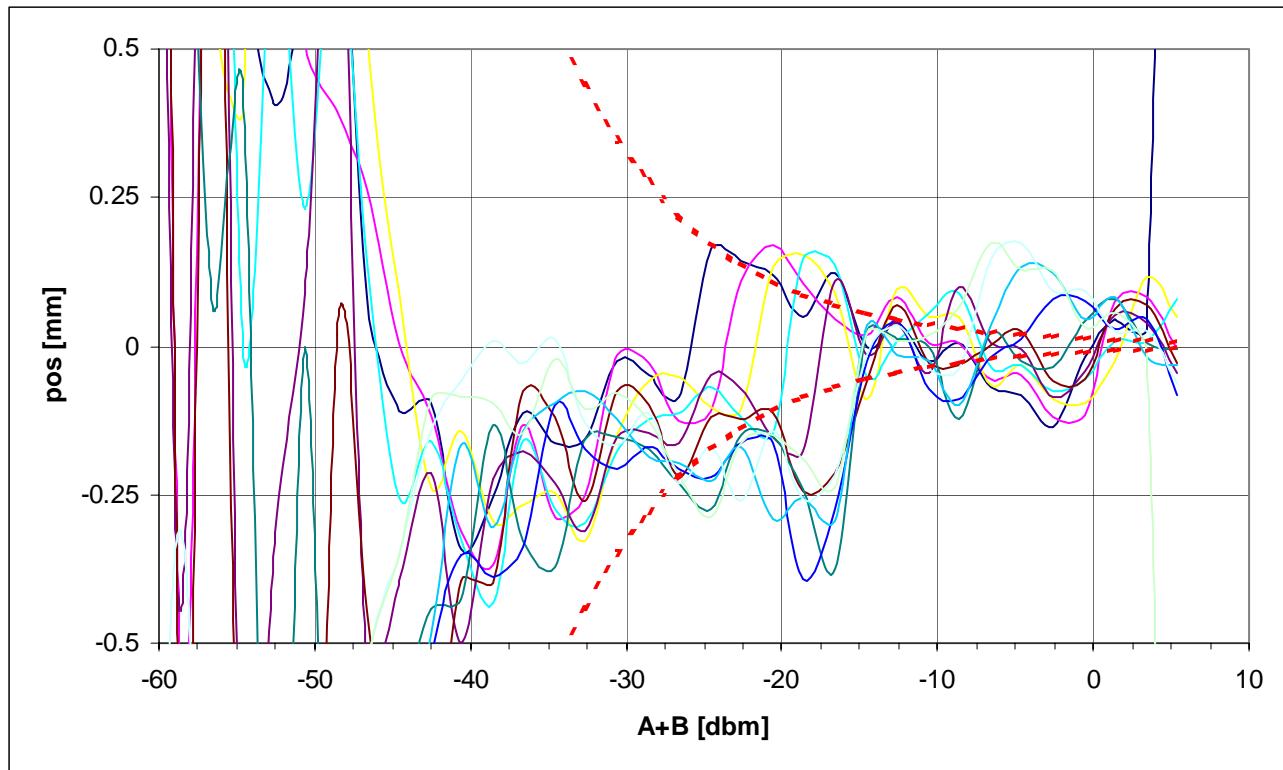
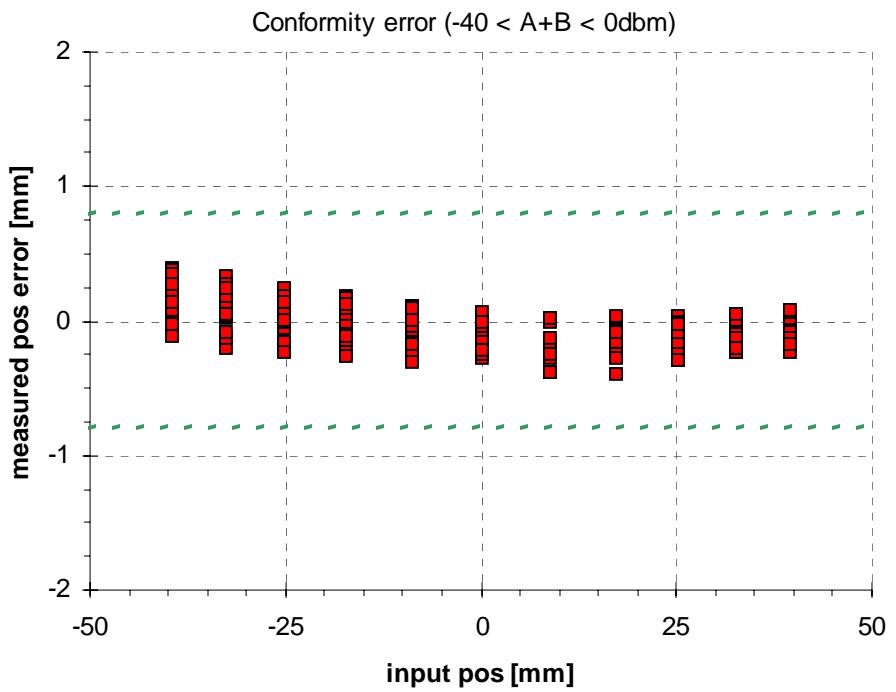
Comparison of the AD6644 and the AD9430 for a full scale input with an MI8bpm (R=75mm).

AD6645	14 bit - 80 MHz	R = 75mm
Fs	4/3 x 53MHz	
N samples	112	
AU	0.1 ps	
SINAD	73.0 db	1.1 um
INL	0.5 lsb	4.6 um

AD9430	12 bit - 210 MHz	R = 75mm
Fs	4 x 53MHz	
N samples	336	
AU	0.25 ps	
SINAD	64.5 db (62.5 db)	1.7 um (2.1 um)
INL	0.3 lsb ( $\pm 1.75$ lsb)	16 um (44 um)

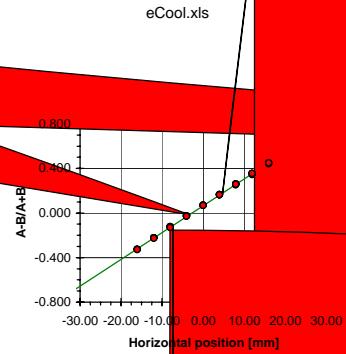
Measured bpm response using AD6645 on Echotek GC814 digital receiver card. Beam signal from arbitrary waveform generator simulating plate signals (dI/dt) from 84 bunches with 2ns sigma t gaussian shape.



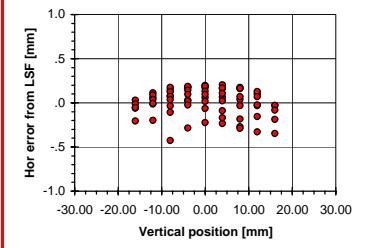
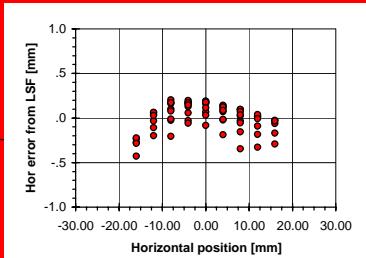
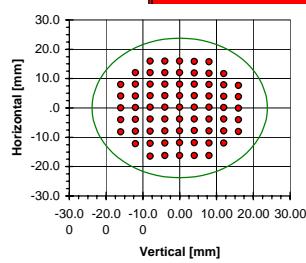


	MI pipe	RR pipe	ec01.1s1H.xls
pipe	hor	ver	res
57	0	24	0
57	2	24	2
56	4	23	4
6	23	6	
8	22	8	
9	22	10	
21	12		
20	14		
18	15		
7	17		
18	18		
20	21		

$db = Sx + O$   
 $S = 41.607 \text{ mm}$   
 $O = .065 \text{ mm}$



0 mm  
 0 mm  
 0.3 deg



-3  
-5  
-6  
-5  
-7  
-5  
-5  
-6  
-5  
-6  
-5  
-53

measured by Alexei Semenov 3/25/02

	db/mm	mm
avg	0.477767	-0.02563
sig	0.004783	0.218045

1x	0.482	0.286
1y	0.478	-0.318
2x	0.484	0.149
2y	0.476	-0.248
3x	0.477	0.077
3y	0.474	-0.221
4x	0.476	0.276
4y	0.467	-0.15
5x	0.482	0.204
5y	0.471	-0.305
6x	0.483	0.171
6y	0.479	-0.245
7x	0.479	0.017
7y	0.472	-0.179
8x	0.483	0.031
8y	0.48	-0.424
9x	0.482	0.089
9y	0.475	-0.148
10x	0.483	0.029
10y	0.469	0.012
11x	0.477	0.282
11y	0.482	-0.338
12x	0.48	0.261
12y	0.475	-0.217
13x	0.483	0.254
13y	0.474	-0.008
14x	0.479	0.175
14y	0.483	-0.085
15x	0.479	0.102
15y	0.469	-0.298
max	0.484	0.286
min	0.467	-0.424

Bin	Frequency
0.46	0
0.4625	0
0.465	0
0.4675	1
0.47	2
0.4725	2
0.475	4
0.4775	4
0.48	7
0.4825	4
0.485	6
0.4875	0
0.49	0

Bin	Frequency
-1	0
-0.9	0
-0.8	0
-0.7	0
-0.6	0
-0.5	0
-0.4	1
-0.3	3
-0.2	5
-0.1	3
0	2
0.1	6
0.2	4
0.3	6
0.4	0
0.5	0
0.6	0
0.7	0
0.8	0
0.9	0
1	0

